to the present data.[8] Further measurements are, however, being made to reduce the statistical errors of the present data, and to extend the results to 160° c.m. and to 100 Mev.

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EVIDENCE FOR CHARGE INDEPENDENCE IN MEDIUM WEIGHT NUCLEI*

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The importance of isotopic spin considerations ($\Delta T = 0$) in "mirror nuclei" (p,n) reactions has been pointed out by Bloom et al.[1] If one goes to nonmirror nuclei such as V^{51}, Cr^{51}, the (p,n) reaction is assumed to go as follows: The incoming proton reacts with an $f_{7/2}$ neutron, exchanges its charge, and is emitted as a neutron. In the initial state there are eight $f_{7/2}$ neutrons available and three $f_{7/2}$ protons. Since, by definition of isotopic spin state (charge independence), all the nuclear interactions within the initial and final nucleus are the same, the Q for the (p,n) reaction between V^{51} ($T=\frac{5}{2}$) and its analog state in Cr^{51} is the Coulomb energy difference. It is the purpose of this Letter to point out that direct-reaction neutrons from the (p,n) reaction on medium weight nuclei do indeed leave the residual nucleus in a state which is the analog of the ground state of the bombarded nucleus.

It was pointed out previously[2] that the energy and angular distribution of the continuum neutrons from the $V^{51}(p,n)Cr^{51}$ reaction are in agreement with predictions of the statistical model of the compound nucleus for proton bombarding energies up to 8 Mev. Using time-of-flight techniques[2,3] to measure the neutron spectra, direct-reaction neutrons are observed for proton bombarding energies above 10 Mev. These neutrons do not come from groups leaving Cr^{51} in low-lying states as might be expected from a simple Born approximation calculation in which one considers only the radial overlap of the wave functions describing the initial and final states. These neutrons are observed to come from a level (or levels) in Cr^{51} at 6.5 Mev.

Neutron spectra at $\theta_L = 23°$ have been measured for proton energies between 9 and 13 Mev using a self-supporting 8-mg/cm^2 vanadium foil and a 10-meter flight path. The neutron spectra for three incident proton energies are shown plotted in Fig. 1. The compound statistical model predicts that if a sufficient number of nuclear levels are involved in both the compound nucleus and the residual nucleus, the energy distribution of neutrons emitted is given by

$$P(E)dE = KE\omega(E_{\text{excit}})\sigma_c(E)dE,$$

where $\omega(E_{\text{excit}})$ is the level density of the residual nucleus at its excitation energy, which is determined by the incident proton energy, the Q value of the reaction, and the emitted neutron energy; $\sigma_c(E)$ is the reaction cross section for the inverse reaction between the excited residual nucleus and a neutron of energy E; and the constant K is a function of the incident proton energy. Assuming that $\sigma_c(E)$ is a slowly varying function of neutron energy, the energy dependence of the level density of the residual nucleus is proportional to $P(E)/E$. The relative neutron spectra transformed to the center-of mass system and divided by the energy of the emitted neutron in the c.m. system are plotted as a function of the excitation of the residual nucleus in Fig. 2. From Fig. 2 it is clear that $P(E)/E$ (allowing for the change in energy resolution as a function of neutron energy) is only a function of the excitation of the residual nucleus up to $E_{\text{excit}} = 6.5$ Mev, indicating the assumption of compound nucleus formation in this region is valid. However, a fluctu-

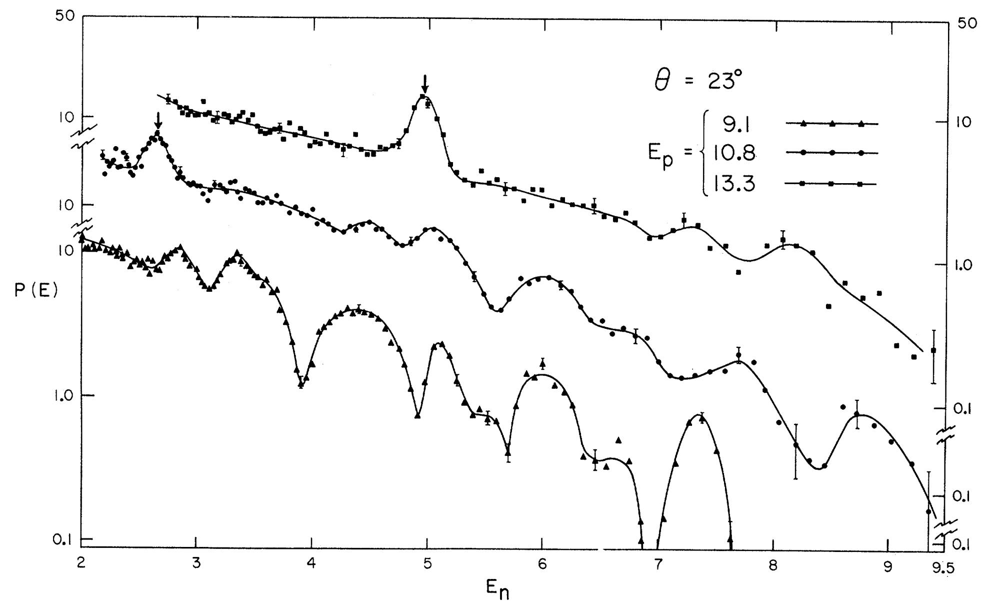

FIG. 1. Neutron spectra from proton bombardment of V^{51}.

ation in level density of a factor of 2 to 3 at $E_{\text{excit}} = 6.5$ Mev with a hundred levels being involved is incompatible with this level (or levels) being populated by a compound nucleus. As one increases the proton bombarding energy the continuum neutron cross section ($E_{\text{excit}} = 6.5$ Mev) decreases

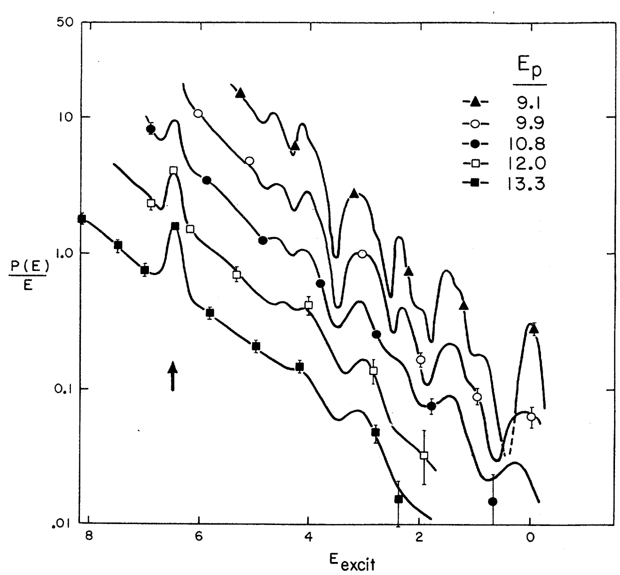

FIG. 2. The neutron spectra transformed to the center-of-mass system and divided by the energy of the emitted neutron are plotted as a function of the excitation of the residual nucleus Cr^{51}. The arrow denotes the position of the analog state.

from 17 mb/sr Mev at $E_p = 10.8$ Mev to 4.5 mb/sr Mev at $E_p = 13.3$ Mev, while the cross section for the "level" remains at 2 mb/sr. The decrease in cross section for the continuum neutrons is in excellent agreement with our previous measurement of the Cr^{51} level density[2,4] and is to be expected on the basis of a compound nucleus while the direct-reaction cross section is expected to vary only slowly with energy which is borne out by the present experimental data. Thus it is concluded that the level at 6.5 Mev in Cr^{51} is excited via a direct reaction.

If one calculates the V^{51}-Cr^{51} Coulomb energy difference using the results of Swamy and Green,[5] one obtains $\Delta E_C = 8.2$ Mev for $R = 1.25 A^{1/3}$ f. This is in excellent agreement with our measured value of 8.0 ± 0.2 Mev. [This is the (p,n) ground state Q(-1.54 Mev) plus the residual excitation in Cr^{51} (6.5 Mev).] Our conclusion is that the level in Cr^{51} at 6.5-Mev excitation is the analog of the ground state of V^{51} and is therefore a $T = \frac{5}{2}$ state.

Additional evidence for analog states is found in the $Fe^{56}(p,n)Co^{56}$ and $Co^{59}(p,n)Ni^{59}$ neutron spectra. Our Q values for the (p,n) reaction to the analog states are again in excellent agreement (see Table I) with the Coulomb energy differences calculated from reference 5.

Further experiments involving additional target nuclei and measurements of the angular distributions of the direct-reaction group are currently under way.

It is a pleasure to acknowledge the assistance of

Table I. Q values for the (p,n) reactions to the analog state.

	Q (measured) (Mev)	ΔE_C (calculated) (Mev)
$V^{51}(p,n)Cr^{51}$ [a]	8.0 ± 0.2	8.2
$Fe^{56}(p,n)Co^{56}$ [a]	8.9 ± 0.2	9.0
$Co^{59}(p,n)Ni^{59}$ [a]	9.1 ± 0.2	9.2

[a]Denotes isotopic spin analog state.

J. W. McClure and B. D. Walker in obtaining the data and of S. D. Bloom in its interpretation.

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PHOTODISINTEGRATION OF POLARIZED AND ALIGNED DEUTERONS*

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Information regarding dynamic and electromagnetic properties of the two-nucleon system obtainable from the photodisintegration of the deuteron can be extended by employing aligned and polarized deuterons. In the present note a partial and preliminary survey of the possibilities is attempted by confining oneself to unpolarized gamma rays and to differential cross sections without a consideration of the polarization of ejected nucleons. Since, as will be seen below, the effects of alignment are quite pronounced, one may hope that the assumptions underlying the usual theories of the photodisintegration process can receive a more thorough test by comparison of theory and experiment even to the limited extent gone into here. The calculations reported on have been made by employing a previously described arrangement[1] in terms of probability amplitudes S_{mi} corresponding to final states with combined proton-neutron spin projection m arising from initial states with spin orientation i. A modified Signell-Marshak potential, referred to as Potential I in reference 1, was used at six photon energies in approximation E in which all transitions of types $E1$, $M1$, and $E2$ are considered in the nonretarded approximation.

The line of orientation axis determined by the direction of fields external to the deuteron is a convenient choice for the quantization axis. In thermal equilibrium one deals essentially with a statistical mixture of magnetic substates with in general unequal population probabilities and without correlation. The calculations reported on are concerned with this somewhat idealized situation. Denoting the relative population numbers of the magnetic substates μ by w_μ with the normalization

$$w_1 + w_0 + w_{-1} = 1, \tag{1}$$

the polarization parameter P_1 and the alignment parameter P_2 in the notation of Blin-Stoyle and Grace[2] are, respectively,

$$P_1 = w_1 - w_{-1}, \tag{2}$$

$$P_2 = w_1 - 2w_0 + w_{-1} = 3(w_1 + w_{-1}) - 2. \tag{3}$$

Equations (1), (2), and (3) determine w_1, w_0, w_{-1} and therefore the w_μ are determined by the specification of P_1 and P_2. Consequently the cross section is expressible in terms of P_1 and P_2. From (2) and (3) and the inequalities $0 \leq w_\mu \leq 1$, $w_1 + w_{-1} \leq 1$ it is seen that $-1 \leq P_1 \leq +1$, the lower and upper limits corresponding to $(w_1, w_{-1}) = (0, 1)$ and $(1, 0)$, respectively. Similarly $-2 \leq P_2 \leq 1$, the lower limit corresponding to $w_0 = 1$ and the upper to $w_0 = 0$.

Parallel and perpendicular arrangements of the orientation axis relatively to the gamma-ray beam direction will be distinguished, respectively, by subscripts l for longitudinal, and t for transverse. In the longitudinal case the differential cross section for protons with unpolarized γ rays is

$$\sigma_l(\theta) = a + bS^2 + cC + dS^2C + eS^2C^2 + P_2[-2g - 2hC - (2i+j)S^2 - (2k+l)S^2C - (2m+n)S^2C^2 - pS^4C - qS^4C^2], \tag{4}$$